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Effects of Fine Sediments on Growth of Juvenile Coho Salmon in Laboratory Streams

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Abstract

Juvenile coho salmon (*Oncorhynchus kisutch*) production (tissue elaboration) was monitored in 12 laboratory streams under six replicate treatment levels of fine sedimentation. Increasing sedimentation suppressed fish production. Our data confirm that habitats of salmonid juveniles, as well as spawning areas, should be protected against fine sediments. Substrate Score, a visual technique for evaluating stream substrate quality, correlated closely with both the geometric mean particle size of the substrate and fish production, and can be easily applied in the field.

The objective of this research was to evaluate the impact of sedimentation on the ability of stream systems to support production (measured as tissue elaboration) or growth of juvenile coho salmon (*Oncorhynchus kisutch*). This research should help establish sediment standards that will more effectively protect stream-dwelling salmonid juveniles.

Sedimentation can affect salmon and trout streams by decreasing embryo survival (Cooper 1965), by reducing stream capacity to produce food organisms (Phillips 1971), and by reducing habitat for juvenile and adult fish (Bjornn et al. 1977). Thus far, the major emphasis by regulatory agencies in controlling sedimentation of salmonid habitat has been to protect spawning areas (Iwamoto et al. 1978). This may not be sufficient protection for those species whose juveniles rear in small streams for 1 or more years. However, the effects of sediment on salmonid production are unclear. Although increased siltation generally reduces invertebrate density and diversity (Cordone and Kelley 1961; Hynes 1970) such effects on food organisms can be masked by opportunistic feeding by salmonids on terrestrial insects. Fine sediments may reduce protective cover for juveniles, especially in winter (Bjornn et al. 1977), but this has not been investigated for many salmonid species.

In the experiments reported here, we attempted to isolate some of the habitat variables associated with stream sedimentation.

Methods

The 12 laboratory streams used in this study were located in a greenhouse at the Oak Creek Laboratory of Biology, Oregon State University, Corvallis, Oregon. Each stream was a wooden trough 3.3 m long, 0.66 m wide, 0.25 m deep, divided lengthwise by a partition with an opening at each end (Fig. 1). Area available to the fish and for insect colonization was 1.55 m^2, which excludes the space occupied by the paddle wheel. Stainless steel paddle wheels driven by electric motors at 12 revolutions per minute maintained constant water velocities. Exchange water from a small spring-fed stream was added to each channel at a rate of 2 liters/minute. Shade cloth was placed over the greenhouse roof during the summer to reduce ambient light and this inhibited periphyton growth in the streams and lowered daytime temperatures in the building. When necessary during the summer, a refrigeration unit was used to cool the exchange water to a temperature suitable for salmonid survival and growth. Water temperature ranged from 0.0 C in February to 20 C in August.

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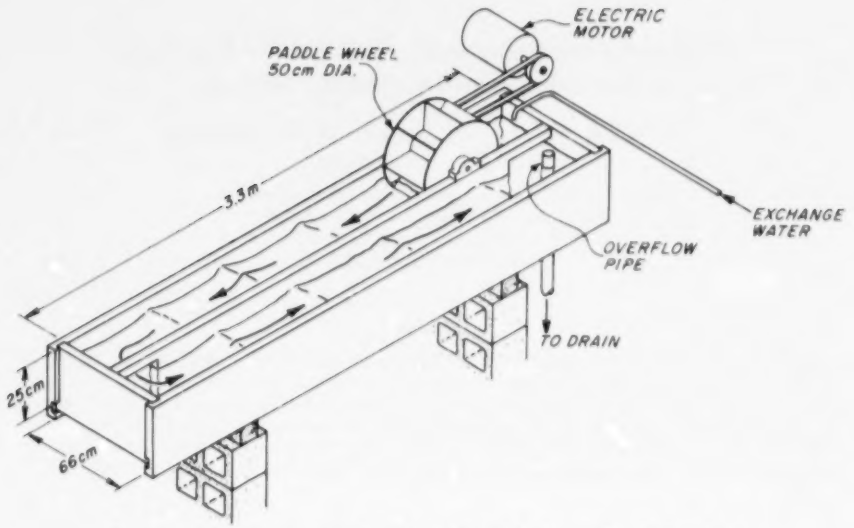

FIGURE 1.—*Laboratory stream channel used for production studies of coho salmon.*

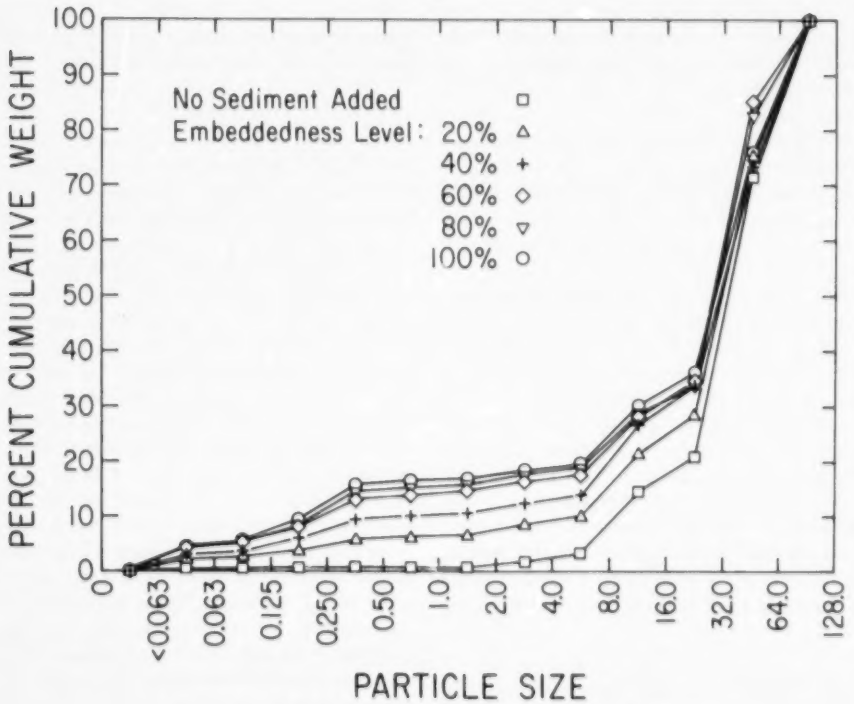

FIGURE 2.—*The cumulative weight of sediment by size in millimeters.*

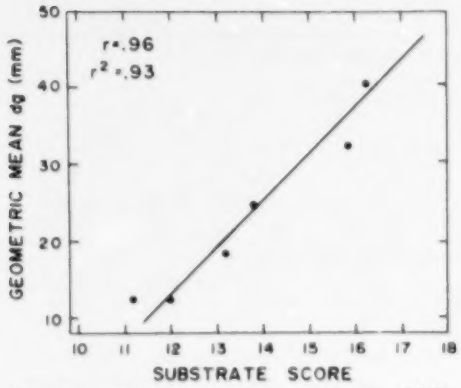

FIGURE 3.—*The geometric mean particle size of laboratory stream sediments (dg) compared to the Substrate Score, the latter obtained by evaluating four sample areas in each channel. Points are means of two stream replications.*

TABLE 1.—*Substrate characteristics and associated ranks for calculation of Substrate Scores. Modified from Sandine (1974).*

Rank	Characteristic
	Particle type or size
1	Organic cover (over 50% of bottom surface)
2	<1–2 mm
3	2–5 mm
4	5–25 mm
5	25–50 mm
6	50–100 mm
7	100–250 mm
8	>250 mm
	Embeddedness*
1	Completely embedded (or nearly so)
2	¼ embedded
3	½ embedded
4	¾ embedded
5	Unembedded

* Extent to which predominant-sized particles are covered by finer sediments.

Two riffles and two pools were created in each stream with river gravel deposits composed of 80% cobble (15–25 cm) and 20% pebble (1.3–2.5 cm) by volume. In October 1977, the streams were dosed with fine sediment (river loam 2.0 mm or less in particle diameter) at six duplicate treatment levels ranging from 0 to 100% cobble embeddedness (the extent to which fine sediments covered the cobbles) in 20% increments (Bjornn et al. 1977).

Water depths of about 5 cm in the riffle and 20 cm in the pools were maintained by standpipes. Periphyton communities developed primarily from algal cells that entered with the exchange water. Deciduous leaves collected in and along the bank of Oak Creek, a nearby natural stream, were added to the laboratory streams to supplement autotrophic food sources for macroinvertebrates.

Macroinvertebrate communities developed primarily from seedings with benthic fauna collected from riffles and pools in Oak Creek. Macroinvertebrates were collected with a kick net (570-μm mesh opening) and a Mundie (1971) sampler (53- and 570-μm mesh opening) and stocked in the streams five times between October 1977 and February 1978. Insect eggs laid in the streams by adults and also entering via the exchange water may have contributed to macroinvertebrate colonization.

On 18 March 1978, eight coho salmon juveniles (51.2 mm ± 0.8, 1.548 g ± 0.062; means ± SD) were stocked in each stream. The fish were recaptured and weighed to three decimal places on a top-loading analytical balance every 28 days thereafter to 30 June (spring experiment). On 18 July, two fish, 64.3 mm ± 2.2 in length and 2.601 g ± 0.186 in weight, were stocked in each stream and reweighed every 14 days thereafter to 13 September (summer experiment). The streams were observed daily; injured fish were weighed immediately and replaced with fish of equal weight, whereas emaciated fish were not replaced. When a fish was too decomposed to be weighed accurately or was missing during regular sampling, an adjustment of the production value was made. Production was estimated as a product of the mean number of fish in the channel and the difference in their mean initial and mean terminal weights (Davis and Warren 1965).

A 0.11-m^2 core sample of substrate was taken every 28 days to determine macroinvertebrate and periphyton standing crops. There were no significant differences among treatments at the start of the experiment for total macroinvertebrate biomass ($F = 0.56$) or total number of individuals ($F = 1.50$) (analysis of variance: $F = 4.39$ for 6,5 df at $P = 0.05$).

The amounts of fine sediment in the streams were measured in two ways. In the first, substrate samples removed during macroinvertebrate sampling were oven dried and mechani-

TABLE 2.—*Production of juvenile coho salmon in 1.55-m² laboratory streams as a function of stream bed sedimentation. Values are means ± SD of two replicates. Values within a column and experiment followed by the same letter are not significantly different (analysis of variance, $P < 0.05$; Duncan's Multiple Range Test, $P < 0.05$).*

Sediment treatment: % embeddedness of cobble	Starting weight (g)	Sampling interval 1 Weight (g)	1 Production ($g \cdot m^{-2}$)	2 Weight (g)	2 Cumulative production ($g \cdot m^{-2}$)	3 Weight (g)	3 Cumulative production ($g \cdot m^{-2}$)	4 Weight (g)	4 Cumulative production ($g \cdot m^{-2}$)
Spring experiment: eight fish per stream; 28-day sampling interval									
0	12.28 ±0.21	15.64 ±0.53	2.16 ±0.48	19.09* ±0.42	4.18† ±0.16	25.42* ±2.34	8.67† ±0.51	20.82* ±0.88	8.78† ab ±0.10
20	12.41 ±0.0	17.70 ±0.76	3.41 ±0.49	21.81 ±2.55	6.06 ±1.64	25.18* ±2.92	8.72† ±2.56	22.53* ±4.65	9.94† a ±3.00
40	12.46 ±0.26	17.33 ±1.63	3.01 ±0.85	22.40 ±0.89	6.31 ±0.41	24.25 ±0.41	7.50 ±0.43	25.82 ±1.29	8.52 ab ±0.66
60	12.66 ±0.31	16.47 ±0.07	2.58 ±0.12	21.00 ±0.51	5.51 ±0.16	22.32* ±1.56	7.13† ±0.09	22.25* ±0.30	7.56† b ±0.06
80	12.03 ±0.20	14.12 ±0.93	1.34 ±0.73	17.08 ±0.39	3.25 ±0.12	17.92 ±0.23	3.78 ±0.28	15.97* ±0.98	3.53† c ±0.08
100	12.46 ±0.18	15.53 ±0.52	1.93 ±0.21	18.56 ±0.70	3.93 ±0.57	19.78 ±1.24	4.72 ±0.92	19.50* ±0.61	4.97† c ±0.10
Summer experiment: two fish per stream; 14-day sampling interval									
0	5.09 ±0.10	5.67 ±0.18	0.38 ±0.05	6.36* ±0.21	0.82† ±0.20	6.49* ±0.07	1.03† ±0.28	7.12 ±0.49	1.43 a ±0.55
20	5.11 ±0.13	5.68 ±0.06	0.37 ±0.04	6.50* ±0.12	0.90* ±0.01	6.89 ±0.05	1.06 ±0.25	6.60 ±0.20	0.87 ab ±0.08
40	5.24 ±0.33	5.54 ±0.35	0.20 ±0.01	5.71 ±0.52	0.31 ±0.12	5.94 ±0.16	0.45 ±0.11	6.29 ±0.71	0.68 bc ±0.67
60	5.21 ±0.18	5.59 ±0.66	0.24 ±0.30	5.87* ±1.24	0.42† ±0.68	6.47* ±2.02	0.37† ±0.57	6.33 ±2.23	0.28 bcd ±0.70
80	5.07 ±0.06	5.27 ±0.13	0.13 ±0.12	5.42 ±0.05	0.22 ±0.07	5.56 ±0.09	0.32 ±0.02	5.43 ±0.07	0.23 bcd ±0.01
100	5.50 ±0.11	5.43 ±0.07	−0.04 ±0.11	5.51 ±0.35	0.01 ±0.30	5.15 ±0.57	−0.23 ±0.43	5.05 ±0.69	−0.29 d ±0.52

* One or more fish died during this interval, resulting in a change in initial and final weights.

† Due to the loss of fish during this interval, an adjustment in fish production was made by the technique of Davis and Warren (1965).

cally sieved to determine particle size distribution (Cummins 1962). From the average cumulative weights of eight core samples at each treatment level plotted against particle size (Fig. 2), geometric mean particle size and percent of fine sediments can be determined (Platts et al. 1979; Shirazi et al. 1979). In the second method, the substrate characteristics in each stream were evaluated at 0.3-m intervals by a visual technique known as Substrate Score (Sandine 1974). The Substrate Score is a summation of four ranks, three concerning the size of substrate particles, the fourth a level of embeddedness. The predominant particle is assigned a rank (Table 1) based on its size; the second most dominant substrate is assigned a rank by the same scale. The third rank corresponds to the size of the material surrounding the predominant substrate particles. The fourth rank is the level of embeddedness of the predominant substrate by the material ranked in the third evaluation. These ranks are summed for a single value corresponding to the Substrate Score. Lower values indicate poorer habitat for benthic invertebrates and, conversely, higher values indicate high quality habitat.

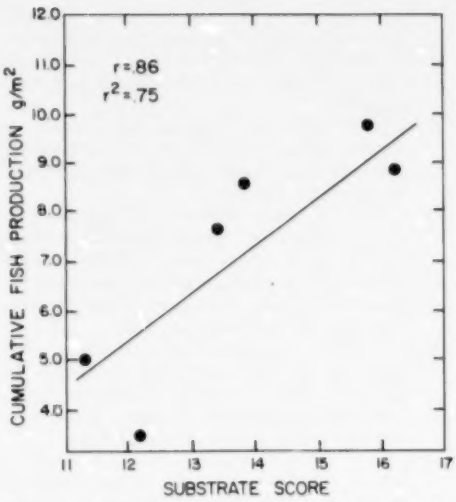

FIGURE 4.—*Total fish production of coho salmon juveniles for the spring experiment plotted against Substrate Score. Points are means of two stream replications.*

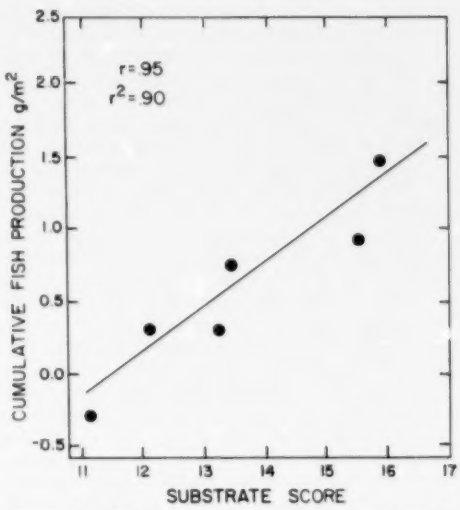

FIGURE 5.—*Total fish production of coho salmon juveniles for the summer experiment plotted against Substrate Score. Points are means of two stream replications.*

A high correlation was obtained when the average geometric mean particle size, a standard but time-consuming measure to determine, of the four sampled sections from each stream was related to the average Substrate Score of these sections (Fig. 3).

Results and Discussion

Production of juvenile coho salmon for each growth period was inversely related to quantities of fine sediment (Table 2). Fish production during the summer was much less than in the spring experiment because most of the macroinvertebrates had already emerged as adults or had been consumed during the spring experiment. Fish production in both experiments was significantly correlated with Substrate Score (Figs. 4, 5). Based on these results, and the high correlation between Substrate Score and geometric mean particle size (Fig. 3), we feel Substrate Score would be a valuable field tool in assessing substrate quality in salmonid spawning and rearing areas. This visual technique is much less laborious than core sampling and mechanical sieving, making it possible to evaluate the quality of a large area of substrate quite rapidly. Visual evaluation of substrate condition is accurate and meaningful for assessment of sediment conditions in salmonid streams (Shirazi et al. 1979).

McNeil and Ahnell (1964) state that salmonid embryo survival is drastically reduced when fine sediments (<0.833 mm) in the spawning gravels exceed 20% by volume of the total substrate. In our experiments, significant decreases in fish production occurred in the 80%- and 100%-embeddedness streams when fine sediments (2.0 mm or less) in these streams were 26 and 31% by volume, respectively, of the total substrates. We conclude, therefore, that the stream-rearing habitats of juvenile salmonids, as well as spawning gravels, require protection from excessively fine sediments.

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